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Cover Photograph—
AH-64D Apache Longbow Mast-Mounted Assembly ballistic vulnerability Live Fire Test shot. This LFT, involving a U.S. Army attack helicopter, was performed by the Army Research Laboratory, Suvivability/Lethality Analysis Directorate at Aberdeen Proving Ground, MD in 1995. Photo by Mr. William Rektorick, Dynamic Science Incorporated.

Director's Notes

Mr. Joseph P. Jolley

I recently attended the American Helicopter Society's (AHS) 54th Annual Forum and Technology Display held in Washington, DC. The theme for the three day event was, "Realizing the VSTOL Vision". The Society's central thrusts are to communicate developments in the advancement and application of vertical flight technology. Forum 54 was impressive, well organized and well executed. With their focus on "vertical flight", tiltrotor and vstol platforms were a featured part of the Forum's agenda.

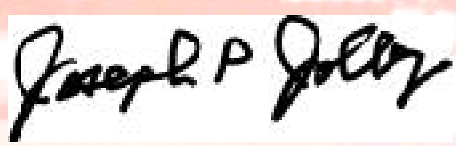
The National Defense Industrial Association (NDIA), in co-sponsorship with the Association of Old Crows (AOC), will be conducting what also is expected to be an impressive event at their annual Survivability Symposium in Monterey, California, August 18-20, 1998. This year's theme is, "Low Observables and Countermeasures - Complementary Capabilities For Aircraft Survivability". For further information, contact Joe Hylan at 703-522-1820.

We recently learned that after 32 years at the Naval Postgraduate School, Professor Bob Ball has announced his intention to retire in October. Although he will no longer be a full time faculty member, he said he does intend to continue teaching survivability and work on the second edition of his text book. One cannot be involved with aircraft survivability and not know Professor Ball! Most of us have a copy of his book and have taken either his survivability short course or his course in residence. Professor Ball has played a fundamental role in establishing and defining the aircraft survivability discipline in addition to being one of its most respected advocates for many years. We are fortunate that he will continue to be involved in the coming years.

The theme of this issue of *Aircraft Survivability* is Live Fire Test (LFT) and Joint Live Fire (JLF). Our objective is to give you an update from each service and from OSD, on these two important programs. Our featured author is Mr. Jim O'Bryon, Deputy Director of Operational Test and Evaluation for Live Fire Test and Evaluation.

Also in this issue we begin a new feature on "Pioneers of Survivability." We will highlight people who we feel have made a significant contribution to aircraft survivability in years past. Our first pioneer is Mr. Jerry Bennett.

We welcome your comments about our newsletter.



An Open Letter on Live Fire Testing

by Mr. James F. O'Bryon

Mr. O'Bryon is the Deputy Director, Operational Testing and Evaluation/Live Fire Testing, Office of the Secretary of Defense. He may be reached via email at jobryon@dote.osd.mil or at 703-614-5408 .

I congratulate the editors of *Aircraft Survivability* for devoting this issue to the subject of live fire testing. Because roughly 52 percent of all defense procurement dollars are currently spent on aircraft, munitions and equipment carried on board aircraft, this focus on live fire testing is certainly justified.

The Live Fire Test and Evaluation (LFT&E) Program, created by an act of the U.S. Congress nearly 12 years ago, requires realistic survivability and lethality testing of our major weapons platforms, missiles, munitions and a report to the defense committees of the Congress prior to the full-rate production decision on any given program. Since its passage, nearly 100 aircraft, ships, land systems, missiles and munitions have either completed LFT&E or are now in the process of planning, conducting or completing their live fire programs.

M&S has played an integral and vital part in LFT&E since its inception over a decade ago.

Since the inception of LFT&E, a debate has been growing over the relative roles of test and evaluation (T&E) and modeling and simulation (M&S) in the LFT&E process. Let me spend a few moments to share my personal thoughts about this ongoing debate.

I will begin by stating that the decision is not choosing exclusively M&S or T&E. Perhaps you have seen as I have, briefing charts that erroneously show a balance scale where M&S is shown as competing against T&E. Nothing could be farther from the truth. M&S has played an integral and vital part in LFT&E since its inception over a decade ago. In fact, I would go so far as to say that LFT&E has integrated M&S more completely into its T&E activities than any other acquisition element within the DoD, and will continue to do so.

From the very beginning, the LFT&E Office has required that pre-shot predictions for each LFT be carefully made and submitted to our office prior to the shot. There are several reasons for this policy. First, requiring the delivery of pre-shot predictions mandates that the best M&S tools be exercised in test planning. Further, these predictions assist in making decisions regarding the placement and use of test instrumentation (e.g., gauges, cameras, thermocouples, fire suppression equipment). The model, coupled with prior test insights, provides the best source of information about what to anticipate during the test. Furthermore, model predictions that indicate the extent of expected damage can be used for sequence testing and make maximum use of limited test resources. Pre-shot predictions also provide a baseline for the adequacy of our current M&S capabilities. Following every shot, a comparison must be made to reconcile differences between model expectations and test outcome. This process is sometimes painful for the M&S community because it often reveals inadequacies in our predictive capabilities. The experience gained in this exercise is essential to improving modeling capability.

To date, approximately two dozen major defense programs have completed all LFTs, and OSD has forwarded its

independent LFT&E reports through the Secretary of Defense to the defense committees of Congress. On virtually every program, surprises were uncovered during testing that had not been adequately considered in the supporting M&S. Another 80 programs are currently undergoing LFT&E or are in the planning stages.

Although empirically derived data can address platform-specific issues, they are inadequate as a predictive tool for future platform designs.

LFT&E is statutory and requires reporting on the test results to Congress, however the LFT&E Office also oversees and funds another effort chartered by OSD in 1984—Joint Live Fire (JLF). The JLF program was chartered to examine, through realistic testing, the vulnerability and lethality of our fielded aircraft and land systems, to gather insights into battle damage repair, to evaluate the adequacy of our vulnerability and lethality M&S, and to help correct discovered weaknesses. This program continues today under the leadership of the Director, Operational Test and Evaluation's (DOT&E) LFT&E Office.

The LFT&E Office also has other efforts directly supporting M&S. Although Joint Live Fire and Live Fire Testing pertain to specific weapons systems under development and those that are fielded or being upgraded, the LFT&E Office is an integral part of another effort—the Target Interaction/Lethality/Vulnerability (TILV) initiative. This effort, which the Director, LFT&E Office along with DDR&E helped to establish back in 1993, is an acknowledgement that OSD and the Services need to work together to formulate their tech-based efforts supporting investigations into damage mechanisms relevant to assessing vulnerability and lethality. The LFT&E Office serves as the TILV secretariat to bring the Services and the Defense Special Weapons Agency (DSWA), formerly known as the Defense Nuclear Agency, together to discuss their plans to support characterizing effects such as blast, penetration, fire and explosion, shock, toxic fumes, directed energy effects and a number of other LFT-related phenomena. This project has been very successful in bringing this diverse community together to discuss and to plan their vulnerability and lethality efforts. Two volumes have been published to date, one a Master Plan covering classical ballistic issues and a companion Master Plan on directed energy effects. This effort is a mix of empirically derived data and "physics-based models," and has a mid-range in time scope, i.e., 5 to 7 years.

Two years ago, the LFT&E Office initiated another effort with a longer time line and with heavier emphasis on physics-based M&S, that acknowledged we will never be completely predictive in our modeling until we move away from empirically based models and move toward models that capture the actual physics and chemistry of the event itself. Although empirically derived data can address platform-specific issues, they are inadequate as a predictive tool for future platform designs. Recognizing this, and the fact that the National Laboratories of the Department of Energy (DOE) possess tremendous computing power and modeling potential, the Director, OT&E and DOE agreed to cooperate through the congressionally established Accelerated Strategic Computing Initiative (ASCI) and the LFT&E Office, to develop more realistic models in support of both the DOE and DoD missions. The ASCI program, which is funded at several hundred million dollars per year (e.g., $520 million in FY99), has the responsibility to assure, through modeling and simulation, that the Nation's stockpile of nuclear weapons is secure and reliable. Because international treaty prohibits our nuclear testing, this effort must rely on realistic modeling and simulation coupled with whatever limited non-nuclear testing can be conducted.

Because the LFT program is "data opportunity rich" and the ASCI program is "model and computing power rich," a cooperative program that enables these two communities to blend their strengths is appropriate and needed.

This is where the LFT&E Office comes in to play. Because the LFT program is "data opportunity rich" and the ASCI program is "model and computing power rich," a cooperative program that enables these two communities to blend their strengths is appropriate and needed. This program provides opportunities for the DOE to advise on the placement of instrumentation in some LFTs to collect necessary data for its models. At the same time, DOE can provide pre-shot predictions to the LFT&E community from its state-of-the-art hydrocodes (which represent the most realistic, most "physics-based" models available today). This unusual but potentially highly beneficial and cost-saving initiative will help advance the entire LFT community to the point where our models and simulations will indeed be both realistic and predictive.

DOT&E's LFT&E Office is supporting concurrent modeling and simulation efforts across the board—empirically, generically, and physically...

As one can see, DOT&E's LFT&E Office is supporting concurrent modeling and simulation efforts across the board—empirically, through the LFT and JLF programs; generically, through its efforts with the TILV program; and physically through its LFT/ASCI cooperative program with the DOE.

As modeling and simulation is much discussed around the community, the LFT&E Office is doing everything within its power and resources to encourage its use, assess its adequacy, and foster its improvement. However, it will take all of us first, to be honest about the current state of the art in vulnerability/lethality modeling and not oversell it to an unsuspecting public; second, to support its continued pre-shot prediction role on every test (not only in live fire but on all testing across the board); third, to assure that test results are carefully compared with model predictions; and fourth, to make model improvements promptly where appropriate.

Does the LFT program support the use of modeling and simulation? The answer is a resounding "yes"! Do we believe that models are now adequate to substitute for realistic testing? The answer is an emphatic "no" at the component and subsystem level and an even more emphatic "no" at the even more complex full-up, system level. We are not alone in this opinion. The Department of Transportation and the U.S. automobile industry as a whole, continue to invest hundreds of millions of dollars annually in full-up, system-level vulnerability testing. Like us, they continue to recognize the necessity of both M&S and realistic testing. In fact, they spend proportionately more per procurement dollar on their auto crashworthiness testing than the DoD does on all of its live fire testing. They recognize, even after more decades of governmentally mandated testing than the DoD's LFT&E program, that M&S are still necessary but still not sufficient. They have learned that, "if you don't test, the model is always right." We want the model to be right. We will not know it is right until our tests and models, grounded in first principles, see eye-to-eye. It will take the efforts of us all to make it happen.

The LFT program is a single program, from the earliest and smallest component test through the most complex, full-up, system-level test. It's an orderly and disciplined process, and one that continues to reveal its value and importance. The congressionally directed Federal Acquisition Streamlining Act moving the activities of the LFT&E Office, including its statutory functions, into the Office of the Director, Operational Test and Evaluation, has enabled many additional economies of scale and continues to yield further benefits.

DOT and the U.S. automobile industry continue to invest hundreds of millions of dollars annually in full-up, system-level vulnerability testing. Like us, they continue to recognize the necessity of both M&S and realistic testing.

In conclusion, I congratulate the Joint Technical Coordinating Group on Aircraft Survivability for its support in efforts to standardize modeling and simulation methodologies over the years. I encourage their continued participation.

Aircraft Vulnerability to Man Portable Air Defense Weapons

by Dr. Al Rainis

Dr. Rainis is a staff specialist for survivability in the Office of the Secretary of Defense, Office of the Director, Strategic & Tactical Systems/Air Warfare. He has taught physics at both West Virginia University and Tri-State University and is the author of more than 30 technical publications. He may be reached at 703-695-3359.

Introduction

Air platforms, by and large, are not designed to absorb a great deal of punishment. A small munition, properly placed, can bring down—or severely damage—an aircraft. However, the difficulty is hitting the aircraft, which, given the value of a modern combat aircraft to the battlefield, has resulted in a variety of weapons being fielded. Of interest here is the man portable air defense (MANPAD) weapon, which generally employs an infrared seeking missile (IR SAM).

MANPADs are a lethal threat. One study[1] provided the data shown in Figure 1. These data, though not necessarily comprehensive, show that the vulnerability of an aircraft to a IR SAM is higher than either small arms/anti-aircraft artillery (SA AAA) or radar-guided surface-to-air missiles (RF SAM). The study suggests that this higher vulnerability to IR SAMs might be a result of DoD's focus on reducing aircraft vulnerability to SA and AAA, with less emphasis on IR SAMS.

The author of the study goes on to suggest that this possible neglect of IR SAMS might ultimately be because of the limitations on the ability of the vulnerability community to analyze and test in the IR SAM arena. This situation may be analogous to the man searching for an item at night under the street lamp even though he lost it in the dark alley. His explanation was that the light was better under the lamp. To complete the analogy, if our test and analysis tools were better we might be able to reduce the lethality of IR SAMS.

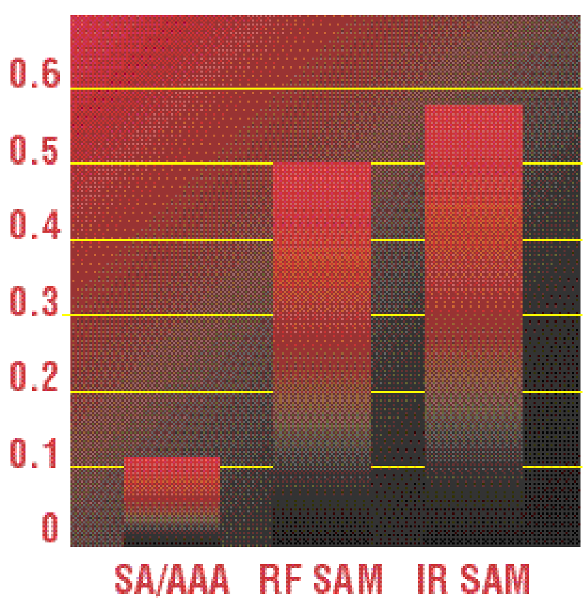


Figure 1. Probability of Kill Given a Hit by Threat.[1]

This study prompted the Office of the Under Secretary of Defense (Acquisition and Technology) to express concern that the acquisition community may be overlooking options to increase the survivability of aircraft against this threat weapon. By and large, our focus has been to avoid a hit by a IR missile. Certainly, the data in Figure 1 could be used to argue that this is the correct approach. However, the author's point does bear investigation to see whether other techniques besides avoiding a hit, are possible. Although—again using the analogy—lighting up the entire world to search for a lost item may not be the most cost-effective approach.

Beefing up the analytical and testing capabilities for aircraft vulnerability to the IR SAM would be an extensive (and expensive) undertaking. In the current economic climate, perhaps the best approach is to ask: "Why do we need the test data and tools?" In other words, before we invest in additional capabilities, we should use the data we have to look at what reasonable and practical design approaches could be pursued to reduce the vulnerability of our aircraft to IR SAMs. The tools should come later to support the optimization of the approaches.

MANPAD Features

Typical of the older IR SAMs is the Soviet SA-7. According to Jane's Weapon Systems 1988–89,[2] the SA-7 is a an infrared homing missile produced by the former Soviet Union and several other countries, which has a maximum altitude of about 4500 m. Variations are being produced by a number of countries. The missile is not large, with a diameter of about 10 cm and with a launch weight of about 10 kg.

At sustainer rocket burnout, a "typical" missile might have a mass of about 7 kg, and a speed that we estimate to be about 500 meters/second (m/s). Total kinetic energy would be about 875,000 joules, although this declines during the missile's flight. Typical warhead weights are about

1 kg, with about half of that made up of high explosive. If the explosive fill was TNT, this could yield 2,340,000 joules. For modern explosives, the explosive fill could readily yield 50 percent additional energy, or more.

A missile striking an aircraft can produce damage in several ways. Although the explosive energy is greater than the kinetic energy of the missile body, it is distributed more-or-less uniformly in all directions—and the explosion may be external to the structure. Hence, the damage may not be appreciable unless the warhead detonates inside the structure. However, wherever it detonates, the explosion will produce a fragment spray that can strike and damage the aircraft. The other source of damage is the remainder of the missile body, which can strike the aircraft and which has the potential to cause extensive damage. The uncertainty concerning the latter damage mechanism may be high, but some data are in hand. Blast and fragment damage, on the other hand, have been studied for some time, although the synergy between these mechanisms may also be uncertain.

So What Can Be Done About the Threat?

It is better not to be hit by the missile, and a lot of effort is expended (properly, in the author's opinion) in doing just that. However, if the aircraft is hit, damage will occur. The focus of this article is to ask what reasonable precautions can be taken to reduce the lethality of the missile strike on the aircraft, and what would such precautions cost?

The Deputy Director, Air Warfare, in consultation with the Deputy Director, Resources and Ranges, has posed the question to the Joint Technical Coordinating Group on Aircraft Survivability:[3] What can be done, in aircraft design or retrofit, to reduce the lethality of a striking IR missile? The corollary to this question is: Are current vulnerability reduction techniques adequate, or are new ones needed in light of the large kinetic energy of the missile body, or some synergistic effect? The answers to these questions will likely depend on the specifics of a given aircraft, or at least, on the class of aircraft—as requested in the tasking Memorandum.

What Response is Envisioned?

There is no preferred solution. Possible responses range from nothing meaningful can be done to mitigating the damage mechanisms, through simply employing current vulnerability reduction practices to developing techniques to shed the kinetic energy of the missile body without damage to the aircraft and reduce synergistic effects.

The expert group convened by the JTCG/AS should keep all options open to discussion, with a caveat. Options to reduce vulnerability of an aircraft are seldom without some side effect. The identification of design or retrofit options for vulnerability reduction should include the costs of exercising the options. This allows the user to make informed choices during the cost as an independent variable[4] trade-off analyses that accompany a new design or a major retrofit.

Another caution is in order. The answers of the JTCG/AS to the question poised by the Deputy Director, Air Warfare, and the Deputy Director, Resources and Ranges, should not come from the Pentagon. Rather, the intent is to provide an assessment by a group of experts, to aircraft program managers and their engineering staffs, for their use in the design or retrofit process.

Conclusion

The immediate answers to the questions may not be the final answers. Every study seems to uncover more questions than the ones being addressed. This is likely to be the case here. And yet, we need to first look at the end game—the practical options to reduce aircraft vulnerability—before acting on those other questions. They may be moot.

For those follow-on questions, the normal competitive funding review process should be followed. However, the OUSD(A&T) will continue to be interested in increasing the overall survivability of our aircraft. That should help raise the priority during the funding review process.

1 Kevin Crosthwaite, "A Modest Proposal," SURVIAC Presentation to OSD, 1998.

2 Jane's Weapons Systems, 1988-89.

3 Memorandum for Chairman, Principal Members, Joint Technical Coordinating Group on Aircraft Survivability, from Deputy Director, Air Warfare, dated February 11, 1998.

4 USD(A&T) Memorandum, "Reducing Life Cycle Costs for New and Fielded Systems," dated December 4, 1995.

Joint Live Fire Pays Something Back

by Mr. Ralph W. Lauzze II

Mr. Lauzze received a B.S. in Mechanical Engineering from Purdue University in 1967 and an M.S. in Mechanical Engineering from the University of Dayton in 1982. Ralph is the AFRL aircraft vulnerability Test Director for Live Fire Test and Evaluation (LFT&E). Ralph is the Air Force Principal Member to the tri-service Joint Technical Coordinating Group on Aircraft Survivability, and is currently its chairman. He may be reached at 937-255-6823.

"What difference does it make?"

Program managers are often asked this question in today's environment of continually declining resources. Current programs must make a significant difference, or they just will not survive. Joint Live Fire (JLF), chartered by the Office of the Secretary Defense (OSD) in 1984 as a Joint Test and Evaluation (JT&E) Program, is one of those programs that continues to make a difference.

The objectives of JLF are:

- gather empirical data on the vulnerability of U.S. systems to foreign weapons and the lethality of U.S. weapons against foreign targets,
- provide insight into design changes necessary to reduce vulnerabilities and improve lethalities of U.S. weapon systems,
- enhance the database available for battle damage assessment and repair, and
- validate current vulnerability and lethality methodologies.

The program consists of aircraft and armor/anti-armor portions. The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) executes the aircraft portion of the program, and the JTCG for Munitions Effectiveness (ME) executes the armor/anti-armor portion, with guidance from OSD/ DOT&E/ LFT&E. JLF is tasked with examining currently fielded weapon systems. The original list of aircraft, which includes the F-15, F-16, F/A-18, AV-8B, AH-64, UH-60, and two foreign aircraft, is being expanded to include systems such as the F-14, C-130, and CH-46/47.

Because JLF uses a tri-service approach, all planning, resources, and results are fully shared, allowing the services, and their contractors, ready access to all the JLF lessons learned.

So what difference does JLF make?

Hindsight suggests the original JLF list should have had two more objectives: "serve as a prototype for developing test and evaluation processes," and "obtain knowledge to allow smart survivability design of future systems." JLF has been delivering on these two objectives since inception, and their value likely overshadows that of the original objectives.

Data collected on JLF aircraft demonstrated that significant fire and explosion protection is possible for a relatively small penalty, pointing the way for protecting future high-performance weapon systems.

Much of the test and evaluation approach now used in aircraft live fire test and evaluation (LFT&E) was developed by the services under JLF, and several shortcomings in our analytical assessment and prediction processes have also been highlighted. For example, our lack of reliable, quantitative predictive capability for dry bay fire and internal fuel system explosion was highlighted early in the program. Recognition of these shortfalls has spurred the development of several initiatives in fire and explosion prediction capability. Similarly, the recent development of test methodology and hardware to ballistically damage and evaluate the effects of helicopter rotor blades, while rotating on the helicopter system, is another JLF first, which will serve as a benchmark for future rotor system evaluations.

While the services' LFT&E Programs examine systems currently in development, such as the F/A-18E/F, F-22, and RAH-66, much of the aircraft vulnerability design baseline for these systems evolved from JLF evaluations. Because JLF uses a tri-service approach, all planning, resources, and results are fully shared, allowing the services, and their contractors, ready access to all the JLF lessons learned. It would be difficult to fully account for the cost saving and cost avoidance resulting from mistakes not made, and tests not required, on new systems as a result of JLF evaluations. This is especially true for new systems that are close in design to the original JLF T&E aircraft, such as the H-60 and 64 variants and the F/A-18E/F.

Because fire and explosion are historically the leading causes of aircraft loss in combat, dry bay fire protection and ullage explosion protection remain a high priority for new systems. Data collected on JLF aircraft demonstrated that significant fire and explosion protection is possible for a relatively small penalty, pointing the way for protecting future high-performance weapon systems. The experience gained from the structural evaluations of the F/A-18, AV-8B, F-15, and F-16 wing and empennage, particularly the composite assemblies, is being directly applied to the F/A-18E/F, F-22, and Joint Strike Fighter (JSF). Similarly, the lessons learned from other JLF evaluations of propulsion, flight control, munitions, etc., are being factored into new system designs.

It has been said that the only way to maximize the benefit of live fire testing is to factor the results directly into system design. JLF has allowed a significantly improved understanding of our fielded systems and is helping apply those lessons to our developmental systems. It has been making a difference for nearly 15 years.

Data from both JLF and LFT&E are preserved at SURVIAC in the Joint Live Fire/Live Fire Test Information System. Additional details may be obtained by calling SURVIAC at 937-255-4840 or DSN 785-4840.

Mr. Wojciechowski is assigned to the Survivability Division of the U.S. Army Operational Test and Evaluation Command, where he is responsible for evaluating the survivability of Army aviation and ground combat systems. From 1986 to 1995, he worked on various LFT&E and Joint Live Fire (JLF) programs at the U.S. Army Research Laboratory. He may be reached at 410-306-0464.

The Case for Full-Up Vulnerability Testing of Combat Aircraft

by Mr. Robert A. Wojciechowski, Jr. and Mr. Tracy Sheppard

Title X, U.S. Code, Section 2366, Live Fire Test and Evaluation (LFT&E) of defense acquisition programs, was passed into law over 10 years ago. This legislation requires full-up, system-level testing of combat-configured systems prior to proceeding beyond low-rate initial production unless full-up, system-level testing has been waived. A perception exists that a waiver from full-up, system-level testing is the automatic “way to go” for combat aircraft. This view may have resulted from the fact that the original legislation (specifically section 2362, which has since been rescinded) applied only to armored combat vehicles. Several early LFT&E programs were vulnerability tests of armored vehicles that gained media attention.

Why do we need to do full-up, system-level tests of combat aircraft? ... because frequently it is only during such testing that deficiencies of an integrated system-of-systems emerge.

With Section 2366, Congress made it clear that all major defense acquisition programs that provided protection to the user were to undergo LFT&E. To emphasize its point, Congress allowed the Secretary of Defense “to reprogram up to one-third of one percent of the total funds approved by Congress for the procurement of a specific system for the purpose of conducting the necessary vulnerability/lethality LFT&E.” It is interesting to note that three Congressmen who led in the sponsorship of the original Live Fire legislation were combat veterans. In fact, one was a fighter pilot in WWII who was motivated by his own combat experiences to ensure adequate vulnerability testing of future combat systems prior to production and fielding.

Why do we need to do full-up, system-level tests of combat aircraft? Primarily, it is because frequently it is only during such testing that deficiencies of an integrated system-of-systems emerge. Witness these lessons learned.

LFT&E Lessons Learned

More than 20 LFT&E programs have been completed to date. From these full-up, system-level tests, we now know that:

- Unexpected things (“surprises”) happen, verifying that “we don’t know what we don’t know.”
- “Cheap” and “soft” kills occur, especially from electrical shorts and software problems.
- Built-in test systems often can’t successfully troubleshoot the battle damage.
- Damaged non-critical components can damage or degrade critical components.
- Failures cascade “up stream” as well as “down stream”.
- Component and subsystem-level tests must be conducted under realistic operating conditions (electrical power, proper mounting, software operating, proper pressures and flows, pressures, dynamic loads, munition velocities).
- Battle Damage Assessment and Repair techniques, provisioning, and training

must be validated using actual damage.

- Less than full-up, system-level LFT&E precludes some important "unknown unknowns" from occurring.
- Stowage and on-board equipment can significantly affect system vulnerability and must be present.
- Only the things that get tested get fixed.
- Spare parts requirements for combat damage were underestimated.
- Visual images in training simulators aren't realistic.
- Munition fuses don't always work as expected.

Can we fully understand the vulnerability or lethality of a system by conducting component-level tests and/or by conducting system-level analyses using modeling and simulation? Perhaps not.

Prior to the start of full-up, system-level testing of the M1 and M1A1 in 1987, the Abrams Tank had already undergone considerable vulnerability testing. Because crew survivability was the top design priority, more than 3000 ballistic tests had already been conducted, including a series of shots against a fully operational prototype vehicle and several system-level tests against the structure.

We should put our efforts into solving some of the challenges that may be limiting our ability to conduct realistic, full-up vulnerability tests of aircraft instead of debating the need to do full-up tests.

The full-up, system-level tests were completed on the M1 and M1A1 in 1987–88 and on the M1A2 in 1991–93. Even with extensive "up-front" vulnerability work that included full-up tests, an average of one design flaw correction recommendation resulted from each full-up, system-level test shot. All of these recommendations resulted from full-up, system-level testing of production vehicles configured for combat (i.e., full complement of stowage, fuel, ammunition, etc.).

To date, 42 percent of the recommendations have been addressed by changing the tank's design and another 25 percent by changing tactics, techniques, and procedures (TTP). Several design changes were implemented prior to the ground phase of the Gulf War. Even though the Abrams has been in production for several years, changes were introduced during production and retrofitted into the fleet. Additional changes will be made as funding permits and the results will influence the design of future combat vehicles.

The Need for Full-up Testing of Aircraft

Recent experience demonstrates that aircraft deployed to combat areas get hit, even though we have complete air superiority and often face unsophisticated air defenses. Although stealth and tactics can and do improve survivability, aircraft will be engaged and hit during some missions. It happens to fighters, bombers, cargo aircraft, and helicopters.

It does not take much imagination to picture some of the same "lessons learned" resulting from hits to an airplane or helicopter. The M1A2 tank, with its 1556 data bus, flat panel displays, computers, thermal imaging systems, position-navigation systems, and turbine engine sounds like it has a lot in common with an airplane or helicopter. However, although they may share some common components, aircraft have many features and attributes that tanks do not. This additional complexity, coupled with the design requirements associated with a system that must fly, further reinforces the need to do full-up aircraft testing. It is probably safe to say that something will be found in a full-up test of an aircraft that we would not want to discover in combat. For example, the Joint Live Fire/Air Systems (JLF/AS) is currently conducting a series of full-up tests of an operational helicopter. A recent test shot caused a sudden drop in gearbox speed. Although the change of speed itself was not catastrophic to the gearbox, a drive component failed after being overtorqued. This cascading damage caused a catastrophic loss of the helicopter.

Another surprising lesson, counter to most current thinking, is that adding armor is not usually the most common nor effective design change to reduce armored vehicle vulnerability. Less than 5 percent of the changes recommended for the Abrams Tank were to increase its armor protection. Some of the design changes resulting from LFT&E include minor revisions to component mounts, default inputs for computer software, combat overrides for critical functions; addition of manual controls, new stowage plans, use of color- and number-coding, and hardening of subcomponents such as switches and circuit cards. The focus of all of these changes was to retain the ability to move, shoot, and communicate following a hit.

Often the argument is made that these tests are a waste of time and resources because they occur too late to affect design. Another argument voiced against full-up, system-level testing is that results are not statistically significant because of the low number of shots and due to the non-repeatability between shots. Thus, the argument goes that changes to systems should not be implemented as a result of the outcomes of full-up system-level tests. However, numerous design changes have in fact been made as a result of the outcomes of full-up, system-level testing. Examples of single data point events providing causality for design changes include bird strikes against the B-1 bomber, the Exocet attack against the USS Stark, and early atomic bomb testing. The only obstacles to vulnerability fixes are perception, attitude, and priority.

Future Aircraft LFT&E

Our weapon systems are becoming more and more complex. The insertion of new technologies and materials into future aircraft increases the need to address system vulnerability and repairability. Certain features being considered for the next generation of aircraft would likely make avionics and electrical components critical. To date, little or no test data are available on these components because they are not flight critical.

Full-up testing is required to understand vulnerability, to prevent cheap kills, and to understand how damaged systems can be most effectively and quickly repaired. These tests also provide the data necessary to accredit computer vulnerability models. We have been surprised in the past and the possibility of being surprised again could actually be increasing because of the complexity, interdependence, and technologies of our weapons systems.

Numerous design changes have in fact been made as a result of the outcomes of full-up, system-level testing. The only obstacles to vulnerability fixes are perception, attitude, and priority.

The time to argue the need to do LFT&E is when we do a full-up, system-level test and are not surprised by the results. Until that time, the answers can only come from full-up, system-level LFT&E programs (or combat experience when it's too late to fix). I think you would agree that we should find our problems before we go to war.

We should put our efforts into solving some of the challenges that may be limiting our ability to conduct realistic, full-up vulnerability tests of aircraft instead of debating the need to do full-up tests. In the meantime, however, we should not let the fact that we cannot do a perfect test prevent us from testing at all. Full-up testing ensures that the test results will generate more answers than questions. It is difficult, if not impossible to ascertain the operational significance of a hit when we are forced to estimate the damage. The escalating per aircraft costs, technology insertion, changing threats, and low purchase quantities make full-up vulnerability tests of aircraft more necessary than ever.

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A pilot from Fighter Squadron 102 gives his F-14B Tomcat a pre-flight inspection on the flight deck of the aircraft carrier USS George Washington. Photo by Petty Officer 3rd Class Joseph Hendricks, USN.

Crew Casualties Minimized Through LFT&E Modeling Effort

by Mr. David Neades and Dr. J. Terrence Klopcic

Mr. Neades received a B.S. in mathematics from Delaware State College in 1975. He currently serves as Leader of the Personnel Vulnerability Team in ARL's Survivability/LethalityAnalysis Directorate. He also serves as the Army member of the JTCG/ME and JTCG/AS Crew Casualty Working Group. He may be reached at 410-278-6335.

Few would argue with the premise that people are the most important "component" of a military weapon platform. Design features that maximize the survival of crew personnel without significantly compromising system effectiveness or lethality are not only desirable—they are essential. Tools that allow the analyst to assess crew survivability early in the system development process permit the risks and benefits associated with design alternatives to be quantified in meaningful, human terms. Recent developments in the tri-service analysis community have set the stage for major improvements in the analyst's ability to make these assessments.

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These improvements form a new, standardized methodology for assessing personnel casualties. The methodology is embodied in the Operational Requirements-based Casualty Assessment (ORCA) model. The ORCA model is the result of a 5-year project involving the efforts of scientists and analysts from the Army, Navy, and Air Force, other government agencies, academia, and private industry. The impetus for this ambitious project was a 1988 conference convened by the Office of the Secretary of Defense, Live Fire Test and Evaluation (now within the Office of the Director, Operational Test and Evaluation) to examine the data and methods employed by the services to assess user casualties. A key conference finding confirmed that the various analytical communities used techniques for evaluating personnel casualties that were so different as to be incomparable. All of this led to the formation of the Crew Casualty Working Group in 1992, which was jointly chartered by the Joint Technical Coordinating Groups for Munitions Effectiveness (JTCG/ME) and Aircraft Survivability (JTCG/AS).

In the past, LFT&E casualty assessments relied on separate applications of several stand-alone models, each of which dealt with a specific battlefield insult. For example, the Army's ComputerMan model was often used to evaluate penetrating injuries, while BRN-SIM, an Air Force code, was frequently used to assess the likelihood of skin burns from thermal exposures. The ORCA model incor-

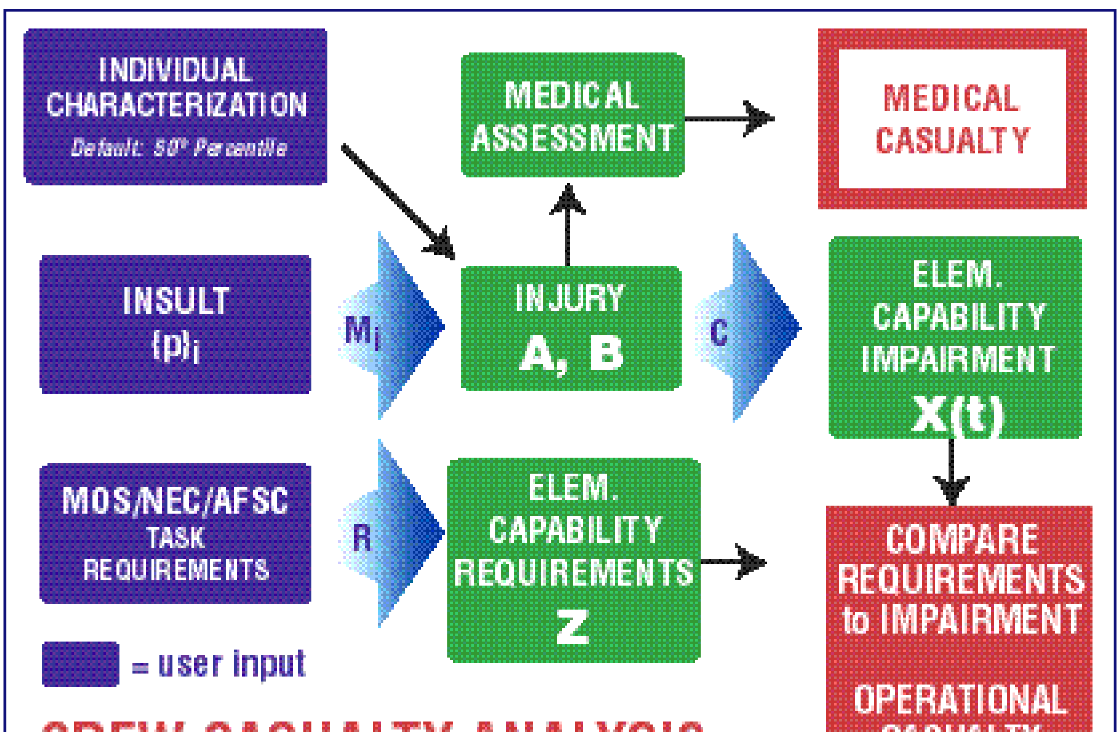

Figure 1. Crew Casualty Analysis

porates the best features of these and several other existing models and combines them in a way that allows consistent assessment of casualties across virtually all platform, task, and threat types.

The foundation of the ORCA model is a new taxonomy for the casualty assessment process implemented in the ORCA computer code. This code allows the analyst to calculate anatomical damage and the effect on individual performance as a result of exposure to kinetic energy, thermal, chemical, directed energy (laser), blast, and accelerative loading threats. In each case, the effect of a computed injury is characterized by the predicted impairment of each of 24 human elemental capabilities (e.g., vision, cognition, and physical strength) as a function of time after injury. Post-injury capability is then compared to capability requirements associated with the individual's military job, task, or mission to determine if he/she is an operational casualty. ORCA users can specify the operational requirement for a military job, task, or mission by selecting from a database library of 18 military occupations (Army, Navy, Air Force, and Marine specialty areas), specific military tasks, or predefined mission scenarios. Users can also build a customized requirement from the available task library.

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Although the determination of medical casualties is not within the charter of the Crew Casualty Working Group, it is essential, to the degree that medical and operational casualty factors are common, that ORCA be consistent with the needs of the medical community. To this end, significant care has been taken to define and record injuries in a way that serves future medical analysis needs. In particular, ORCA determines and tracks each injury's Abbreviated Injury Score (AIS), an injury characterization system common throughout the medical community.

ORCA is scheduled for beta testing later this year following completion of verification and validation efforts. Besides becoming the standard methodology for evaluation of casualties in Live Fire Test and joint live fire programs, this methodology is being investigated for use by US Army STRICOM, US Navy Ship Vulnerability Program, and NATO.

Dr. Klopcic was graduated from Knox College and commissioned in the Chemical Corps in 1964. He received his Ph.D. in experimental nuclear physics from the University of Notre Dame in 1970. He is currently the U.S. Army member on the Executive Committee of the JTCG/ ME Vulnerability Working-Group. He may be reached at 410-278-6322.

Radio Frequency Weapons — 21st Century Threat

by Mr. W. Mark Henderson and Mr. David A. Schriner

Background

The U.S. Navy is concerned about the electromagnetic environment, both known and evolving in which it must operate. The harshest known environments are created by the Navy's aircraft carrier deck, hostile termination end game, and some aircraft radars. Military systems that operate in these environments are required to undergo an electromagnetic environmental effects (E^3) test process. E^3 Tests deal with the interaction between a system (weapons system in our case) and the in-service operational environment produced by other systems necessary to carry out the total mission. A charter for this work is currently shared by the Naval Surface Warfare Center, Dahlgren, the Naval Air Warfare Center Aircraft Division, Patuxent River, and the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake/Pt. Mugu. The Naval Medical Research Institute (NMRI) detachment at Brooks Air Force Base has the Department of Defense (DoD) lead for radio frequency (RF) human effects, also known as hazards of electromagnetic radiation to personnel (HERP).

Another type of testing for fielded and new weapons systems in the acquisition process included both Joint Live Fire Test and Evaluation (JLFT&E) and Live Fire Test & Evaluation (LFT&E). JLFT&E is chartered by the Office of the Secretary of Defense (OSD); LFT&E is a congressionally mandated requirement. The LFT&E legislation requires realistic survivability testing by firing munitions likely to be encountered in combat at the system

The harshest known environments are created by the Navy's aircraft carrier deck, hostile termination end game, and some aircraft radars.

Mr. Henderson is an Electronic Systems Engineer in the Plans and Project Office as the High Power Radio Frequency/Microwave Test Director for the Junction Ranch Test Range of the Metric and TSPI Division. He received a B.S. in electronics engineering technology from California Polytechnic State University in 1984. He joined the Naval Air Warfare Center(NAWC) in 1988. He may be reached at 760-939-7434.

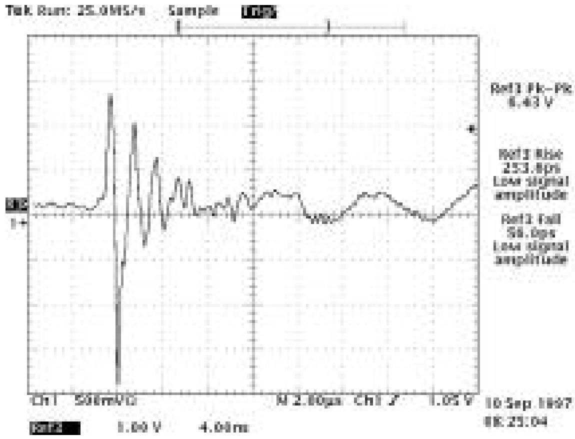


Figure 1. Radiated transient Electromagnetic Waveform.

configured for combat—with the primary emphasis on testing vulnerability with respect to potential user casualties (Title X U.S. Code Section 2366). The term "munition" includes the category known as directed energy. U.S. weapons systems are becoming more complex with the integration of advanced computer-based technologies. Although these advanced systems provide the warfighter with a technological advantage over our adversaries, there are trade-offs. Computer-based light-weight systems must be protected from the threat of "soft" or partial kills. High power transient electromagnetics (HPTE) is a revolutionary threat going through an evolution. The subject of much controversy over the past several years, the remainder of this article focuses on this new directed energy weapon or, as the title states, radio frequency weapons.

The Technology

There are two basic types of high power microwave (HPM), narrowband and transient wave, also known as ultra-wideband. Narrowband devices generate an RF signal made up of sine waves either in a group or "pulse" of a few to many or, in some cases, continuous waves (CW). This wave shape appears on a spectrum analyzer as a small width, hence the name "narrow-band". Transient wave signals do not radiate sine waves but rather an electromagnetic spike-like waveform of very narrow width. A Fourier transform of the waveform shows that it occupies a rather large instantaneous spectral bandwidth. For this reason, it is generally referred to as an ultra-wideband (UWB) signal, as is a swept CW signal of the same bandwidth. To avoid confusion in the nomenclature, such waveforms can be referred to as "transient wave signals."

Much information exists in both the classified and open literature concerning narrowband HPM systems and their use in vulnerability and susceptibility measurements and effects. Development and testing have been going on for years. Several novel types of RF generators have been developed specifically for this type of RF weapon. The types of signals generated lend themselves well to conventional RF modeling and analysis approaches. Many types of antennas can be used to radiate this type of signal effectively. Examples include dish types, horns, dipoles, phased arrays, and several in the class of frequency dispursive designs, which can be used because of the sine wave nature of the generated signal.

Transient wave HPM systems are quite a different case. Conventional modeling and analysis techniques are difficult, if not impossible, to use because they cannot accommodate the UWB waveform. Only a single class of antenna can be

Figure 2. AH-1S Test Bed

used to radiate such signals and the effects of multipath are quite different than for narrowband systems. Application of this type of waveforms to HPM weapons work is very new, thus there is little information in the literature. For this reason it is worthwhile to list a few

of the peculiar characteristics of this type of waveform.

The radiated waveform, as shown in Figure 1, is normally generated by applying a fast step-up voltage to a transient electromagnetic (TEM) horn antenna. The horn will differentiate the applied waveform and generate the radiated signal. These applied step waveforms can be generated by switch closures, spark-gap closures, or solid state device switching. Rise times ranging from fifty to a few hundred pico seconds are typically generated, with voltage swings from a few hundred volts for mechanical switches, to tens of thousand volts with comparable rise times for solid state switches, and voltage swings greater than a megavolt with slightly longer rise times with spark-gap switches. Generally such voltage swings are produced from sources of low impedance ranging from parts of an ohm for some solid state switches to the low tens of ohms for spark-gap switches.

The extremely fast voltage swings into horn antennas produce rather high peak powers and radiated field strengths. A megavolt per meter (or more) field strength at the antenna mouth can be obtained. Peak radiated powers in the multi terawatt levels could be achieved with repetition rates in the 1000 pulses per second(PPS) range. These systems are generally specified with a figure of merit related to this field strength. A system with a figure of merit of 200 kilovolts/meter (kV/m) will produce field strengths of 20 kV/m at 10 meters and 2 kV/m at 100 meters.

Antennas other than a horn will produce a radiated signal representative of their impulse response. A dipole, for example, will radiate a damped sine wave of many cycles while a log-periodic dipole array will radiate a chirped sine wave relative to its bandwidth. A helical antenna will radiate a sine wave of rotating polarization.

When transient wave signals are received by any antenna other than a TEM type, the output waveform will also be determined by the impulse characteristics of the receiving antenna and will result in a time-distortion of the received waveform. If, for example, a radio receiver antenna on an aircraft were illuminated by a transient wave signal, the antenna output would likely be a signal easily processed by the receiver regardless of where it was tuned. The receiver output would likely be a large audio pulse and a train of such signals would make the radio unuseable. Transient wave signals make very good jamming waveforms because they occupy the entire bandwidth of the targeted receiver, and their peak power is such that receiver circuit recovery (after initial receipt) further hampers receiver operation.

The Threat

Recent discovery of a new electromagnetic environmental condition has matured to the point that justifies its inclusion in the LFT&E process. It is called transient electromagnetic device (TED) technology. Demonstrated peak power levels up to hundreds of terawatts are easily obtained at repetition rates up to 1000 PPS. Because of these extremely high physical parameters, testing fully operational systems against this threat must be done at an open air test range that provides containment of this type of directed energy. The Junction Ranch test range, located at the NAWCWD, China Lake, was selected to conduct the Joint Live Fire Testing of Radio Frequency Weapons. The Junction Ranch facility provided the following inclusively unique parameters:

Recent discovery of a new electromagnetic environmental condition has matured to the point that justifies its inclusion in the LFT&E process. It is called transient electromagnetic device (TED) technology.

Mr. Schriner is an industry and DoD consultant with Schriner Engineering. Although retired after 42 years of Civil Service, he continues research and development in the area of transient electromagnetic generation devices as well as collection systems. He may be reached at 760-384-4579.

Figure 3. High Power Microwave Device (HPMD)

Figure 4. LLNL Instrumentation Hardware.

- Low backscatter test environment
- Remote location from population centers
- Extensive controlled clear airspace
- Minimum of spurious electromagnetic radiation interference
- Infrastructure to support tests
- On-station technical expertise
- Physical security
- Scheduling efficiency

Preliminary testing has shown that some military weapon systems and commercial infrastructure platforms are highly susceptible to this new waveform. The primary application for TED is weaponization. This new environmental threat is not listed in the Strategic Threat Assessment Report (STAR) for new and currently deployed military systems; however, the authors and technical community expect to see it available for use in the field of battle against high-technology assets within the next 2 to 3 years.

The test was a cooperative effort between DoD and Department of Energy laboratories to develop and demonstrate the methodology required to perform RF weapons survivability testing for the LFT&E Office.

The Test

NAWCWD, in anticipation of the expected exposure to this threat recently participated in the first Directed Energy JLFT using both conventional and TED HPM. The test was a cooperative effort between DoD and Department of Energy laboratories (i.e., NAWCWPNS, China Lake, Air Force Research Labortory, Army Research Laboratory, and Lawrence Livermore National Laboratory) to develop and demonstrate the methodology required to perform RF weapons survivability testing for the LFT&E Office.

The H5 high power TED was provided by the Air Force Research Laboratory (AFRL), Kirtland AFB. The H5 is one of a series of hydrogen spark- gap switch sources developed at AFRL. The RF energy radiated by this device is an E-field with an ultra wide spectral bandwidth.

The HPMD was provided by the Army Research Laboratory (ARL), Adelphi, MD. It provided an L-band source where the radiated RF energy is an E-field with a narrow spectral bandwidth. The average power of the radiated waveform was much greater than that of the HPTED source.

Lawrence Livermore National Laboratory (LLNL) was responsible for taking measurements of the incident (external) electric field power density on an AH-1S Cobra Helicopter during the RF Joint Live Fire Demonstration at China Lake to allow mapping of threat, distance, and effect.

Conclusion

Transient wave sources and weapons are a new technology not well understood by many in the HPM community who have been working with narrow-band systems for years. The observed effects during this test series were supportive of the statement that “complexity equates to vulnerability”. The complexity of the signal’s propagation and interrelationship with mechanical structures

(both targets and antennas) makes it very difficult to model. For this reason, there is doubt regarding the utility of modeling results, particularly with regard to the operational engagement related issues for each system.

Open-air testing of military systems against likely RF weapon threats should be used to identify potential problem areas. The need to test strike asset platforms first is critical. The type of test performed at China Lake for the LFT&E Office last year is the best way to resolve this issue.It is best to identify problems in a non-hostile environment where we can fix them easily.

Better Insensitive Munitions for Aircraft

by Mr. Leo Budd

Mr. Budd is an Aerospace Engineer in the Survivability Divison of the Naval Air Warfare Center. He received a B.S. in Aerospace Engineering from Tri-State College in 1970. He may be reached at 760-939-3328 or via email leo_budd@imdgw.chinalake.navy.mil.

In the early 90s the JTCG/AS sponsored a tri-service project on aircraft weapons bay vulnerability. One major finding was that current insensitive munitions (IM), although safer than munitions from 25 years ago, still represent a significant hazard to aircraft. Internal carriage of munitions to reduce susceptibility brings with it an increased vulnerability associated with reactions of stores to unplanned stimuli.

Since 1993, the issues of aircraft vulnerability and IM have been discussed at workshops sponsored by the NATO Insensitive Munitions Information Center (NIMIC). In 1995, on NIMIC's request, I co-chaired a workshop discussion group on non-detonation reactions such as torching (jetting) and burning. We concluded that munitions users have a need for enhanced insensitive munitions that have even fewer reactions to unplanned stimuli than current IMs. The reduction or elimination of ignition and burning was considered a priority for future generations of IMs.

To promote better IMs for reducing weapon platform vulnerability, I requested an audience with the NIMIC staff in 1996 to further discuss the issues. Other interested parties from the UK, France, and the Netherlands were invited by NIMIC to join in the discussion. The concerns we expressed were used by NIMIC in refining their plans for a two-part workshop in 1997. At the spring 1997 workshop session, I showed a video of the damage a burning rocket motor, ignited by a projectile, can do to an aircraft. NIMIC recognized that this presentation galvanized their workshop participants to seriously consider major changes in IM. I was asked to co-chair a continuation of the munitions "response descriptors" discussions at the fall session. There we prepared quantitative descriptors of munition responses to unplanned stimuli and proposed them to NATO to replace the qualitative descriptors in use today. We also proposed that a new generation of IMs be sought by creating new, more stringent, categories or levels of IM. One of these proposed levels is the ultimate IM, one with no reaction from the energetic material in the munition.

In January 1998, Mr. Anthony Melita, Deputy Director, Strategic and Tactical Systems, Munitions at OSD, held a meeting with all the US personnel who attended the 1997 NIMIC workshops. The lessons learned and the issues for discussion were documented with the intention of bringing them before the Tri-Service IM Integrated Product Team (IPT). A new initiative for better IMs may well be coming for the United States. It is interesting to note that Mr. Melita is working with NIMIC regarding future international IM requirements upgrades and was recently chosen to be the new Chairman of the NIMIC Steering Committee.

The Air Force Research Laboratory and SURVIAC hosted a JTCG/AS workshop in

Figure 1. A ballistic threat hit a rocket motor inside this aircraft's weapons bay igniting the motor.

Figure 2, left. Upper rocket motor was hit by a ballistic threat and ignited.

Figure 3, right. Upper motor is igniting the lower motor in a cascading damage effect.

January 1998 to discuss the aircraft probability of kill from onboard munitions. The uncertainty of vulnerability assessments when munitions are involved was identified as an unresolved problem for today's survivability community.

The Live Fire Test & Evaluation Office in OSD has expressed interest in coordinating with the IM IPT on mutual concerns. This may eventually lead to reduction in the munitions hazards that affect LFT program decisions.

FAA Uncontained Engine Debris Mitigation Program

by Mr. Charles E. Frankenberger

The Systems Vulnerability Branch at China Lake is currently supporting the Federal Aviation Administration (FAA) Technical Center to define the uncontained engine debris threat and evaluate existing DoD vulnerability assessment tools as they may apply to uncontained engine debris safety assessments to be used by the commercial sector. This task falls under the FAA's Catastrophic Prevention program. Our experience is based on prior testing under the Joint Live Fire (JLF) program, of operating jet engines to determine their ballistic tolerance to realistic combat threats. This JLF experience led to development of capabilities to ballistically test full-up jet engines, as well as their disks as single components operating at typical speed. A JLF-funded device, referred to as the "Spin Fixture" was used. Based on this experience, we were asked to participate in a workshop sponsored by the FAA called "Uncontained Engine Debris Characterization, Modeling and Mitigation." As a result of our interaction at that workshop, we were later requested by the FAA to submit a proposal to manage this effort.

The product of this effort is a design process consisting of analysis and methodology tools that will assist commercial aircraft and engine designers in minimizing the vulnerability of civil turbine-powered aircraft to uncontained engine failure.

An interagency agreement with the FAA Technical Center was established to conduct testing and manage the Uncontained Engine Debris Mitigation Program. The agreement spans 5 years and has an estimated value of $4 million. The product of this effort is a design process consisting of analysis and methodology tools traditionally used in the aircraft survivability discipline that will assist commercial aircraft and engine designers in minimizing the vulnerability of civil turbine-powered aircraft to uncontained engine failure. The process is similar to military aircraft vulnerability reduction activities. Data are collected to characterize the uncontained debris and the damage it causes. In instances where data are unavailable, tests will be conducted to further define the debris velocities and penetration characteristics. An initial assessment will be conducted using existing vulnerability analysis tools to further define the prediction code requirements and measures of effectiveness. Existing analytical tools (COVART and FASTGEN) will be modified to specifically address the uncontained debris scenario and provide the desired measures of effectiveness. A detailed methodology/analysis tool will be delivered at the end of the 5-year effort. Major activities within the program include debris characterization, damage characterization, development and verification tests, assess containment and mitigation technologies (including materials), and damage prediction model development. This product will be available as a design tool for civil airline manufacturers to build more survivable aircraft.

F/A-18E F414 Engine Specification Qualification and Live Fire Test

by Mr. Charles E. Frankenberger

The F/A-18E/F F414-GE-400 turbofan engine successfully completed fuel ingestion specification qualification testing and live fire test (LFT) at NAWCWPNS Weapons Survivability Laboratory, China Lake, California. The F414 is the first engine to require fuel ingestion specification compliance testing during development. This engine vulnerability was first demonstrated under the Joint Live Fire Program by testing the F-100 and F-404. Specification tests included quick dump and steady flow fuel ingestion. LFT tests included controlled damage tests to evaluate the engine control system, additional fuel ingestion testing, and ballistic tests.

Fuel ingestion testing incorporated a full-scale F-18E/F replica inlet built at China Lake. With this level of detail incorporated into the test setup, additional fuel ingestion tests were conducted in support of the aircraft fuel system development. Testing was conducted to simulate fuel leakage of the bleed cell 4 heat air-fuel exchanger to determine whether the fuel flow rates would go undetected by the leak detection system, which could cause the loss of the engine or aircraft.

State-of-the-art infrared (IR) cameras were used to determine the location of fuel ignition in the engine's bypass duct. These cameras, in addition to internal afterburner cameras, provide a clear picture of the ingestant flow ignition location.

As a result of the successful conduct of this test series and the prior F414 Bladeout test conducted here, the Survivability Division has been asked to provide engine Non-Destructive Inspection (NDI) capability in support of F/A-18E/F flight test aircraft coming to China Lake for weapons integration testing based at VX-9. This is the first time the Systems Vulnerability Branch has been asked to support the fleet in operational test and evaluation at the organization maintenance level. Because this is still a developmental engine and we have conducted the prior testing, we possess the software and expertise to digitally control the engine with a state-of-the-art that has outpaced the squadron-level maintenance capability.

Mr. Frankenberger has worked in the propulsion field at NAWCWPNS for 12 years, including 8 years in missile propulsion on programs including Tomahawk, Harpoon/SLAM and Advance Air-to-Air Missile. He has worked Engine Vulnerability issues for the past 4 years conducting ballistic tests on turbine engines under JTCG/AS, JLF and LFT efforts. He may be reached at 760-939-3681.

F/A-18E Live Fire Test Logo. Logo design by Neal Barry, Aegir.

The F/A-18E Super Hornet. Photo by Vernon Pugh.

F/A-18E Arrives at NAWCWPNS China Lake to Support Live Fire Testing

by Ms. Susan L. Hennigan

Ms. Hennigan is a technical writer with the Technical Information Division of the Research and Engineering Competency at the Naval Air Warfare Center Weapons Division, China Lake, CA. She holds a B.A. in Literature/Writing with a minor in Scientific Perspectives from the University of California, San Diego. She may be reached via e-mail at susan_ hennigan@imdgw.chinalake.navy.mil or by telephone at 760-939-3671. .

Figure 1. The F/A-18E, designated Test Article SV52, arrives at NAWCWPNS China Lake. Photo by Marty Krammer, Survivability Division.

Figure 2.. Look Out Below! Test Article DT50 undergoes drop testing at the Boeing Company in

The arrival of the F/A-18E at the gates of Naval Air Warfare Center Weapons Division (NAWCWPNS) China Lake on May 12 was hailed by Al Wearner, Marty Krammer, and Ronnie Schiller from China Lake's Survivability Division; representatives from the Boeing Company, St. Louis, Missouri and Northrop Grumman, El Segundo, California; and media journalists and photographers. The aircraft traveled from the Boeing Company facility in St. Louis to China Lake on a 91-foot-long, double low-boy, flat-bed truck (see Figure 1). Despite El Nino's mercurial effect on weather conditions and the unpredictable hazards of traffic, the F/A-18E's ground trek was without mishap and a day ahead of schedule.

Boeing and Northrop Grumman representatives were on hand to assist Survivability Division personnel in off-loading the F/A-18E and in performing a thorough inspection of the aircraft and other deliverable ship items. Once the inspection was completed, the Navy officially accepted delivery of the F/A-18E from the Boeing Company. This particular F/A-18E is the third engineering and manufacturing development (EMD) airframe.

The aircraft's journey to China Lake was one of many (though not necessarily short) steps toward ensuring that the F/A-18E/F will be the most survivable and effective aircraft in the Navy's inventory. The current configuration of the airframe, designated SV52 by the aircraft manufacturer, has had a rough but rewarding life.

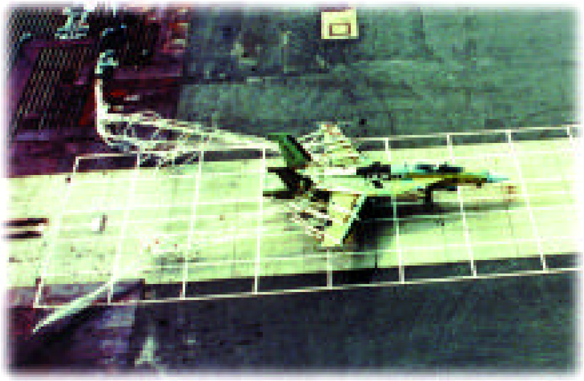
The airframe was originally designated DT50, which identified it as a drop test article. After drop tests were completed at the Boeing Company facility in St. Louis (Figure 2), the airframe was reconfigured and redesignated ST56 in preparation for barricade-engagement testing (Figure 3) at Naval Air Warfare Center Aircraft Division (NAWCAD) Lakehurst, New Jersey. Upon completion of the barricade-engagement tests, the test article was shipped back to St. Louis and again cocooned inside the Boeing plant, to re-emerge several months later as SV52, the live fire test (LFT) article.

As SV52, the aircraft will undergo the final round of a lengthy and complex Live Fire Test and Evaluation (LFT&E) program designed to ensure the F/A-18E/F's combat survivability. In accordance with LFT&E legislation, SV52 is scheduled to undergo testing at Weapons Systems Laboratory (WSL) in June of this year. This final round of comprehensive tests will include testing the aircraft's empennage, wing, and fuselage. Tests will focus on meeting two primary objectives:

- to validate the results of previous testing of surrogate aircraft, subsystems, and small- (including pre-production hardware) and large-scale components,
- to investigate the effects of ballistic impact on systems and/or components of the F/A-18E/F that differ significantly from the previously tested F/A-18A/B/C/D aircraft.

Testing of the F/A-18E has been planned to identify any remaining unknown vulnerabilities that may require design

changes before the aircraft enters full-rate production. The SV52 tests mark the culmination of live fire testing for the F/A-18E/F program.



The F/A-18E/F aircraft is nearly 25 percent larger than the C/D variant. Despite its larger size (resulting from an increased wingspan and longer fuselage, which increase the aircraft's overall surface area), the vulnerable area of the F/A-18E/F aircraft has not increased over that of the current F/A-18C/D aircraft. This improvement in F/A-18E/F vulnerability has been accomplished through the incorporation and further enhancement of vulnerability-reduction features found in the F/A-18C/D. Additionally, the E/F's designed-in electrical power and cooling margins extend the Hornet's ability to accommodate technology advancements as required.

The F/A-18E's recovery payload has increased by 3,500 pounds (to 9,000 total pounds) over that of the F/A-18C. This extra weight margin allows the F/A-18E to land back on board the carrier with larger numbers of either training ordnance or high-value "smart" weapons. Although specifics vary depending on the mission scenario, the range and endurance of the "bigger and better" F/A-18E/F have increased significantly over those of the F/A-18C/D across the warfighting spectrum.

After completion of LFT&E, results will be reported to Congress, fulfilling the requirements of the LFT&E law and allowing the aircraft to go into full-rate production. LFT results will also be incorporated into updates of vulnerability assessments of the aircraft.

Army Research Lab's Airbase Range Facility Update

by Mr. Patrick Swoboda

The U.S. Army Research Laboratory (ARL) Survivability/Lethality Analysis Directorate (SLAD) Airbase Range Facility conducts component- through system-level experiments on fixed wing aircraft and helicopters to generate data for vulnerability/lethality (V/L) analyses, model and simulation support, and vulnerability reduction. Because of the unique experimental facilities and the resident extensive knowledge of aircraft vulnerability, the Airbase Facility has also developed into the Army's premier V/L experimental facility for conducting Army aircraft Live Fire Testing (LFT) and Joint Live Fire (JLF) programs. Recently, the following Army LFT programs were conducted at the facility: Apache Longbow (AH-64D) and the Special Operations Aviation (SOA) Aircraft (SOA) (MH-60K and MH-47D). Currently, the Airbase Facility is performing the JLF AH-1S Tail Rotor Driveshaft and Fuel System tests.

Specialized features at the facility include the following: an outdoor environmental blast pad for large blast/fragment warhead firings; a covered, full-scale dynamic turbine engine and helicopter drivetrain test pad; indoor and outdoor

St. Louis, MO to confirm the airframe's ability to withstand landing loads. Photo courtesy of Andrew Hesketh, Boeing Company.

Figure 3. GOTCHA! Test Article ST56 is captured by the barricade at NAWCAD Lakehurst. Photo courtesy of the Visual Information Branch, NAWCAD Lakehurst.

Figure 1. Mobile Airflow Generator

Mr. Swoboda is an engineer with the U.S. Army Research Laboratory, Aberdeen Proving Ground, MD. He received his B.S. in Engineering Physics from Rensselaer Polytechnic Institute and his M.S. in Applied Physics from the Naval Postgraduate School. He may be reached at 410-278-2192.

Figure 2. Mi-24 "Hind" Subsystem Testing

Figure 3. Airbase range facility overview.

ballistic ranges for component and system-level experiments; an Environmental Protection Agency (EPA) approved spill containment and fluid separator system; a mobile airflow generator capable of producing winds as great as 500 knots; and a centralized instrumentation and control building.

The Environmental Blast Pad Area is a concrete pad 6 ft thick with a 100 ft by 100-ft primary pad and a 50 ft by 50 ft secondary pad. A full-scale aircraft (with airflow) can be operated on this pad. High explosive charges as large as 100 lbs can be detonated to determine the vulnerability of full-up aircraft, subsystems, and components. The perimeter of the primary pad has drains that feed into an EPA-approved spill containment system. The fuel, oil, and other hazardous materials then are separated from water used for fire fighting. The hazardous materials are recycled to the maximum extent, and the separated water is used for fire extinguishing on future experiments.

The Structural Research Building is an 85 ft by 50 ft bunkered building with a structural floor attachment system, overhead crane and two 60 ft roll-open doors in the front and rear walls, providing an enclosed structure for the testing of whole aircraft or aircraft sections against projectiles and high explosives. This building is capable of withstanding blast from detonations as large as 25 lbs of high explosive with the doors open and 5 lb with the door closed. The facility is an approved security vault that has accommodated destructive tests of aircraft and other vehicles.

The Propulsion Thrust and Drive Dynamics Pad is a partially sheltered concrete pad for use in controlled damage and gunfire experiments on operating power plants and power trains. It is 100 ft by 50 ft with thrust stands, cableways, and security shrouds. A suite of dynamometers with associated controls and mobile water supply supports shaft engine operations.

All range tests are controlled and managed from the instrumentation/control blockhouse. Wiring from the three experimental areas travels through underground conduits and terminates in this building. From here, the data acquisition and control equipment monitors and controls the airflow generator, turbine engines, and other subsystems being tested. In addition, this facility is home to the mobile airflow generator (MAG), which is capable of providing as much as 500 lbs of air with low speed velocities from surface wind effects and helicopter airspeeds to subsonic speed regimes from air-flow over fixed wing aircraft. The MAG can direct as much as 500 knots of air onto a test article. The MAG consists of two Pratt & Whitney JT3D turbofan engines and is fully mobile, with a 700-gallon fuel capacity, enough fuel to provide 39 minutes worth of airflow for each engine.

The vast experience of on-site personnel and state-of-the-art technologies combine to create an exceptional environment for conducting full-scale LFT and JLF programs as well as sub-scale experiments focusing on VL phenomenology

Pioneers of Survivability — Gerald "Jerry" Bennett

by Mr. Kevin R. Crosthwaite

Not all pioneers wore coonskin caps, carried a rifle named "Betsy," and blazed a trail with an axe. The pioneers of aircraft survivability did not live quite so long ago, or quite so roughly (they usually stayed in cheap motels). One such survivability "pioneer" is Gerald Bennett. As a pioneer, Jerry saw a vision of less vulnerable aircraft, carried a slide rule, and blazed a trail with more than 165 technical reports and papers written.

After his 1960 graduation from the University of Michigan, Jerry went to work in the Air Force Flight Dynamics Laboratory (AFFDL). He was assigned to prediction of air-blast and thermal effects on aircraft and missiles. His first task involved positioning three helicopters to make measurements of the combined blast waves resulting from detonation of three large high-explosive charges. Reanalysis, and increased standoff distances, resulted when he learned that he would be riding in one of those helicopters!

Another experiment involved simulating the thermal pulse from a nuclear weapon and the effects on pilots with and without thermal curtains. This experiment used an F-100 with a bank of quartz lamps to produce a cockpit flux level that would, at worst, produce a slight sunburn. Volunteer pilots were run through the simulator and many of them used the pulse cut-off switch. After retesting with thermal curtains in place the pilots returned to their squadrons and both maintenance and use of these curtains went up substantially! Jerry also participated in making cloud physics measurements for estimating wind shears in what he hopes was the last above-ground nuclear detonation in the continental United States as well as in Pacific field testing.

Jerry accepted a promotion into the Operations Research Division of the Systems Engineering Group in June 1966 where he worked in developing and applying analysis techniques for non-nuclear survivability/vulnerability. The Army's Ballistic Research Laboratory (BRL) became overwhelmed with Army projects, so he began generating Air Force (AF) vulnerability data. He also developed an air-to-air gun model, a missile end game model, and a model for evaluating vulnerabilities of parked aircraft to mortar and rocket attacks. He worked "both sides of the fence," defining the warhead/fuze for the AF's proposed short-range missile. He became the AF representative on the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) Aerial Target Vulnerability Panel.

A 1967 reorganization resulted in Jerry joining the Deputy for Development Planning (ASD/XR) where he worked in the Systems Integration, and later the Aircraft Design Branch. In addition to the F-X (F-15) and A-X (A-10), he worked on a host of conceptual systems including the Long-Range Combat Aircraft (LRCA), Compass Cope, and the Supersonic Penetrating Attack Missile (SPAM). To get inputs for vulnerability analyses he worked very closely with anyone that would cooperate with him at the AFFDL. This cooperation resulted in tests on many aircraft components including static engines to estimate ballistic penetration, and avionics boxes to estimate ballistic penetration and vulnerabilities. The tests were considerably more informal than those of today. Each testing group waited until the current tenant of the range had run its test and brought in its specimen. Back then, the testing and analysis communities were tightly organized—the same people did both!

One of his most satisfying "paybacks" came at a post-Iraq war Aircraft Battle Damage Repair (ABDR) Symposium where an A-10 pilot said that he wanted to thank him for working to make it a tough aircraft.

Jerry performed survivability/vulnerability analyses on many aircraft employed in Southeast Asia as part of various quick response analyses. He worked with the System Program Offices (SPOs) and the AFFDL to write test plans for conducting ballistic tests to support hardness level development. Jerry participated with Jerry Wallick and various AF personnel in a study to develop expected damage levels and associated resources and non-standard repair techniques for the A-10 aircraft. Their timing was quite good—shortly after they completed the study and moved the (irreplaceable) data out, the SPO burned down! One of his most satisfying "paybacks" came at a post-Iraq war Aircraft Battle Damage Repair (ABDR) Symposium where an A-10 pilot said that he wanted to thank him for working to make it a tough aircraft. Working with support from Wright Laboratories (specifically, Don Voyls), and contractors, Jerry developed and applied a generalized technique and supporting databases for ABDR estimation.

As the vulnerability task leader on Air Force Systems Command (AFSC) Mission Analyses, Jerry was responsible for developing, or causing to be developed, the vulnerability and end game estimates for a mix of existing, growth, and conceptual systems. He served as the Assistant Director for the Chemical/Biological Warfare Defense Mission Analysis with the responsibility for contracted/in-house model development and application. For the High Energy Laser (HEL) Mission Analysis he developed estimates of various types of aircraft and missile kills and of associated “keep-out” ranges for no damage to the laser-carrying aircraft.

Jerry worked on AGARD/AASC Study #1 on Physical Vulnerability of Aircraft. Continuing work with his German and English counterparts resulted in analysis technique comparisons and test data exchanges. One product was a joint German/US Analysis Workshop at Wright-Patterson AFB where contractors and government personnel presented papers on analysis techniques and results. In exchange for the USAF’s donation of some hydraulic fluid to the Royal Air Force (RAF) (who tested it), comparisons of flammability results for several different types of American and British fluids were obtained at essentially no cost to the USAF. The British also contributed draft external blast test data on reasonably modern aircraft structures, which Jerry used to support development of an analysis technique.

Throughout Jerry's career, he has been involved in the JTCG/AS. He helped form the JTCG/AS and served a long term as chair of the JTCG/AS Vulnerability Assessment Panel and subsequently as the AF Chair of the JTCG/AS Methodology Subgroup.

In March 1993 he accepted the AF’s downsizing offer and retired. In June 1993, he went to work for Booz Allen & Hamilton in the SURVIAC. Since then he has worked on various studies, including a transport armor placement analysis, two AAA model (RADGUNS) parametric studies, C-17 and C-130J vulnerability analyses, a High Explosive Incindiary (HEI) vulnerability computer program comparison, and a series of studies related to development and documentation of aircraft component vulnerability (Pd/h) estimates.

Jerry and his a wife Harriet have raised two sons. He participates in the Boy Scouts, his church, and the local food bank, Enon Emergency Relief. He also helped his wife teach computer skills to her third-grade students. He owes all his (limited) computer skills to the teaching of his sons. A current high priority effort involves spending quality time with his sons and their families, and especially spoiling his four grandchildren.

F-22 RAPTOR Live Fire Test and Evaluation

by Mr. Michael R. Weisenbach

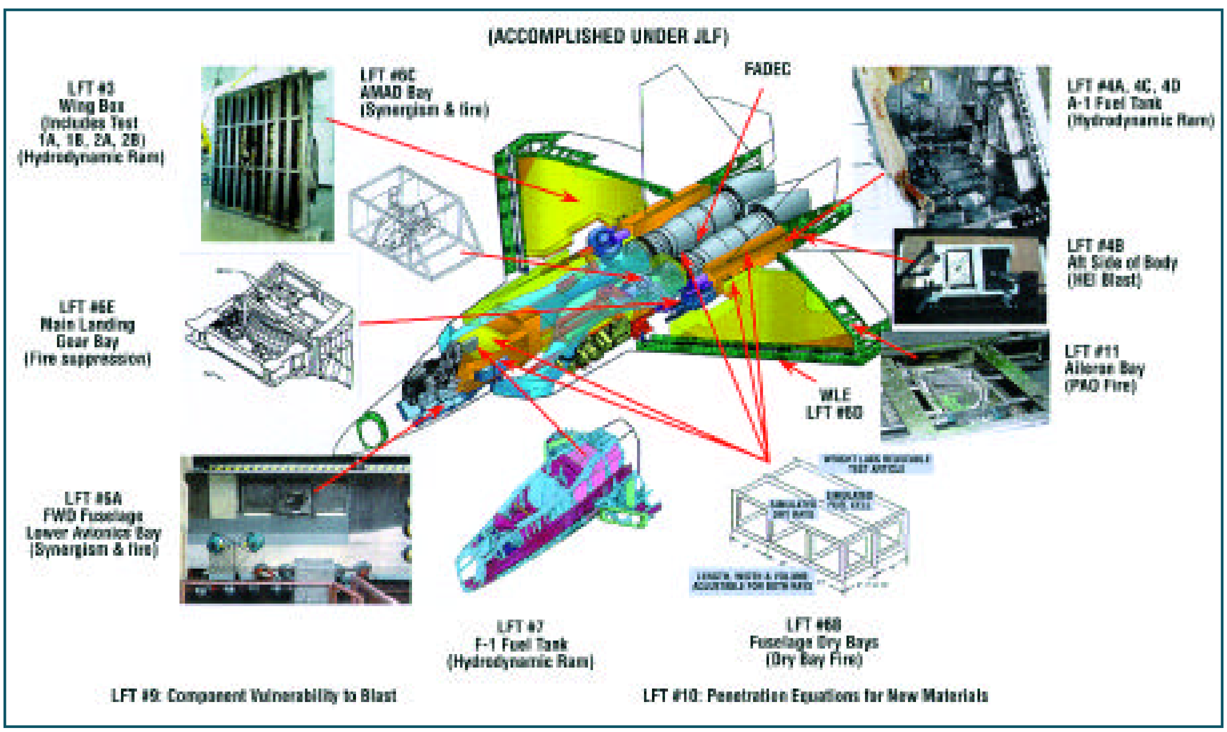
The F-22 Live Fire Test and Evaluation (LFT&E) program is based on a detailed systems engineering approach that integrates quantitative requirements definition, historical combat data and other test data (e.g., Joint Live Fire [JLF]), modeling and simulation, proven vulnerability reduction design features, and a rigorous test approach. The broad objective for the F-22 LFT&E program is to assess the vulnerability posture of the F-22 when hit by enemy fire, including ballistic and directed energy threats. This objective is accomplished by vulnerability analysis and reduction of analysis uncertainty through testing. Some testing under the F-22 LFT&E program is also being performed to investigate basic phenomena where current methodologies and data bases are inadequate.

Figure 1 illustrates the areas on the F-22 that have been or will be subjected to live fire testing. As can be seen, the F-22 will be tested from nose to tail and wing tip to wing tip by the time the program is completed. Where photographs are shown in Figure 1, the tests have been completed. Tests #6B, #9, and #10 are nearing completion; all other tests are in the planning phase.

The F-22 LFT&E has had a significant impact on the design of the air vehicle. In particular, the early testing performed under LFT # 1A&B (4 spar wing box), and 2A&B (8 spar wing box) demonstrated damage that was much greater than predicted. Because the testing was done early enough in the program, the wing design team was able to use the information generated in these tests to design a much more robust wing. These tests are all included under LFT #3, the final test in this series, and will be a validation of the design changes based on the lessons learned in the early tests. This final test will be conducted on a full production-representative wing.

Likewise, the tests performed in LFT #4 (Aft Side of Body/A-1 Fuel tank) led to a re-design of the structure in the aft side of body. The new design substantially increased the capability of the F-22 to withstand potential combat damage mechanisms. Other design changes were driven by the results of LFT #11 (Aileron Bay) and #6A (Forward Fuselage, lower avionics bay). These tests investigated the ability of fragments and projectiles to initiate fires in avionics equipment cooled by a liquid avionics coolant, polyalphaolefin (PAO). After demonstrating fragments and projectiles could create sustained fires in PAO, a shutoff valve was installed that could detect a leak and shut off the coolant flow.

Because of the model-test-model approach taken in the F-22 LFT&E program, many improvements have been made to the vulnerability analysis tools, in



Mr. Weisenbach earned a B.S. in Aerospace Engineering from the University of Notre Dame in 1984 and almost immediately began his association with the JTCG/AS. Since 1995, he has served as the chairman of the Vulnerability Assessment Committee under the Methodology Subgroup. He may be reached at 937-255-4343 or weisenmr@xr.wpafb.af.mil.

Figure 1. F-22 Live Fire Test Coverage.

Mr. Murphy is the AFRL C-130 Vulnerability Reduction Program Manager. He received his B.S. in Mechanical Engineering in 1986 from the University of Cincinnati and his M.S. in Mechanical Engineering from University of Dayton in 1991. He may be reached at 937-255-6302 or via email at JOHN.MURPHY@va.afrl.af.mil.

addition to the significant reduction in F-22's vulnerability.

The results of LFT #9 (Component Vulnerability to Blast) will provide valuable data on the vulnerability of specific components to the blast effects of high explosive (HE) projectiles. The components tested in this series were selected because little was known about how they would react to blast. Components from the YF-22 Prototype Air Vehicle (PAV) were used in this test to obtain data on state-of-the-art components that will be used in modern air vehicles.

Preliminary results from LFT #10 (Penetration Equations for New Materials) have already been incorporated into the vulnerability code COVART. This test series was conducted under the F-22 LFT&E program because the penetration equations used at the beginning of the F-22 program could not accurately predict the penetration characteristics of some of the advanced materials used to build the F-22. Coupons of F-22 representative material have been subjected to fragment and projectile impacts to determine mass loss and velocity slowdown through these unique materials.

In summary, the F-22 LFT&E program has significantly reduced the uncertainties regarding the vulnerability assessment of the F-22 Air Vehicle. The tests have validated several design changes and vulnerability reduction features that have been applied to the F-22. All F-22 LFT&E test reports are being made available to the vulnerability analysis community through the JLF/LFT Test Information System at the Survivability/Vulnerability Information Analysis Center (SURVIAC).

Aircraft Survivability Research Facility: A Vital Asset for JLF and LFT&E

by Mr. John J. Murphy, Jr., 1Lt Audra M. Cake, and Mr. Daniel C. Cyphers

The Air Force Research Laboratory (AFRL) Aircraft Survivability Research Facility (ASRF) at Wright-Patterson Air Force Base, with roots as a World War II armament technology facility, has become a world class survivability/vulnerability facility. The AFRL Survivability and Safety Branch (AFRL/VACS) uses the facility to research, develop, test and evaluate, and transition technology related to fuels, fires, explosions, armor, threat characteristics, hydrodynamic ram effects, inlet fuel ingestion, structural damage analysis, airflow effects on composite structures, weapon system development, and individual aircraft components. ASRF-accomplished programs have had significant joint service, non-DoD, and international impacts.

In recent years, AFRL has become an integral joint live fire (JLF) and live fire test and evaluation (LFT&E) test facility. The ASRF is comprised of six ranges with varying capabilities (see Table 1). Range 1 (indoor) is a simulation and calibration facility. Threat simulator development, specialized test range instrumentation systems, and material and component ballistic tolerance evaluations are typical efforts conducted in this facility. Ranges 2 and 3 are essential to JLF and LFT&E programs. Range 2 is used for such programs as fuel cell inerting, hydrodynamic ram evaluations, ballistic flammability, material and component ballistic tolerance, and threat characterization. Typical efforts at Range 3 include replicated and production test flight hardware ballistic evaluations including high-speed airflow, flight load simulation, and operating systems. A 1992 upgrade created Upper Range 3 by adding five TF33-P-102A engines and a high-capacity crane rail system, significantly enhancing free jet airflow velocity and quality, increasing effective airflow wetted area from 9 to 25 square feet, and expanding capacity to install and remove specimens. Lower Range 3 uses the original two TF33-P-102A engines. Range 3 was further upgraded in 1996, elevating the roof and crane rail to accommodate complete wings and large fuselage sections.

Range 4 (indoor) is dedicated to basic impact physics and launch technologies research. Low velocity light-gas, intermediate velocity powder and high velocity electrothermal-chemical guns are used. Range A (indoor) is used for impact physics

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Figure 1. Aircraft Survivability Research Facility at Wright-Patterson Air Force Base, Ohio.

research. Engine nacelle fire extinguishing agents are developed, validated, and transitioned via simulated inflight testing in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS). The ASRF uses a modern data acquisition system to precisely conduct test programs and record, process, analyze, refine for presentation, and archive data for future use. System-critical components include a Nicolet dedicated Ethernet acquisition network; numerous thermocouple, strain gauge, pressure transducer, accelerometer, and flash detector channels; Scanivalve airflow mapping system; holographic laserography; flash X-ray systems; high-speed photography (up to 10,000 frames per second [frps]), videography (black and white and color to 1,000 frps), infrared camera system; and optical disk and writable CD-ROM drives for data archiving.

ASRF has demonstrated its utility for successful accomplishment of JLF and LFT&E programs. Its various range configurations, threat testing spectrum, fuel capacity and conditioning capability, airflow capability, modern data acquisition system, fire suppression capability, and on-site design and fabrication expertise make it a user-friendly facility.

Past ASRF live fire test programs include JLF F-15 and F-16 testing conducted from the mid 80s to early 90s, Advanced Medium Range Air-to-Air Missile (AMRAAM) lethality LFT&E testing in 1989, and AC-130U Gunship vulnerability LFT&E testing in 1992. In addition, a comprehensive C-17A LFT&E program was conducted at the ASRF between 1991 and 1995. Issues successfully addressed by the program included C-17 wing leading edge dry bay fire and wing structure hydrodynamic ram vulnerability.

In 1996–97, an aggressive B-1B LFT&E program was accomplished at the ASRF. This program included successful evaluation of wing leading edge, trailing edge, and fuselage dry bay vulnerability; ullage explosion vulnerability; and wing hydrodynamic ram vulnerability. A JP-8 characterization test series generated empirical data required to model ullage fire and explosion. A 40mm high explosive projectile characterization test series was also successfully completed.

F-22 LFT&E program ASRF tests began in 1995. Areas being investigated include wing hydrodynamic ram vulnerability; synergistic effects and fire vulnerability in the aileron, forward fuselage, aircraft-mounted auxiliary drive, wing leading edge, main landing gear, *Mr. Cyphers is a senior engineer for Skyward, Ltd. He received his B.M.E. in 1986 and his M.S. in Aerospace Engineering in 1991 from the University of Dayton. He may be reached at 937-431-1580.*

and wing attachment dry bays; and F-1 fuel tank fire and explosion vulnerability.

The C-130 Vulnerability Reduction Program (VRP) is in progress, and Phase I will be conducted in 1998–99. C-130 wing leading edge, engine area, and trailing edge dry bay fire extinguishing technologies will be developed, validated, and transitioned. C-130 VRP Phase II will evaluate ballistic damage effects on the new six-bladed C-130J composite propeller in 1999–2000. A C-130 engine nacelle ballistic fire extinguishing evaluation will be initiated in 2001. This ASRF program will evaluate the adequacy of C-130 engine nacelle fire extinguishing under combat conditions.

A JLF C-130 Wing Hydrodynamic Ram Evaluation program has recently been established. Production C-130H wings will be tested at the ASRF in 1999. JLF F-117 strategic planning is now under way. An ASRF test program will be formulated based on the strategy developed.

The ASRF is the critical tool largely responsible for successful Air Force JLF and LFT&E program accomplishment. Development, validation, and transition of survivability enhancement technology at the ASRF will ensure in-service, developing, and future systems perform and survive in their intended operational environment. The ASRF contribution to significantly enhanced aircraft survivability will continue to have a positive impact on military weapon systems and non-DoD systems into the next century

Figure 2. Aircraft Survivability Research Facility Ranges.

RANGE	YEAR ACTIVATED	THREATS	CAPABILITIES
1	1980	Small arms through 30mm HEI Static detonations through 57mm HEI Shaped charge fragment simulator Sabot launched fragments (up to 40mm)	Size (indoor): 12'x65'x10' high Simulation and callibration facility Threat loading and storage facility
2	1971	Small arms through 40mm HEI Shaped charge fragment simulator Sabot launched fragments (up to 40mm) Light gas projectile launchers 100 to 12,000+ fps velocities	Size (outdoor): 27'x300'x26' high Threat characterization Fire suppression: CO_2 system, water deluge/spray Environmental protection system
3	1971	Small arms through 30mm HEI Shaped charge fragment simulator Sabot launched fragments (up to 30mm) Limited shotline angle on 40mm Light gas projectile launchers 100 to 12,000+ fps velocities	Size (semi-enclosed) Upper - 40'x25'x39' H or 50' L Lower - 40'x25'x50' L 450-500 knots airflow (up to 5 TF-33-P102A turbofans) 5'x5' nozzle (upper), 3'x3' nozzle (lower) Fuel conditioning -40 to +240°F, variety of fluids, 2,000 gal. Fire Suppression: CO_2 system, water deluge/spray Environmental protection system
4	1991	Small arms through 30mm API Sabot launched fragments (up to 30mm) Light gas, powder, electrothermal-chemical, and rail launchers 100 to 10,000 fps velocities	Size (indoor): 10'x175'x9'H Ballistic impact physics, launch technologies research
A	1996	Spheres and sabot launched fragments Precision launch light gas gun 50 to 3,000 fps velocities	Size (indoor): 25'x120'x25'H Impact physics research facility
Aircraft Engine Nacelle Facility	1992	Ignition source: propane/air mixture and spark ignitor	Aircraft Engine Nacelle Fire Test Simulator Fire detection/suppression, hot surface ignition Generic design - applicable to many engines Accomodates various flammable fluids, extinguishing agents, test conditions Airflow: 2,7 lbm/s to 14 lbm/s

Army Helicopter Ballistic Vulnerability Testing—Past, Present, & Future

by Mr. Stephen F. Polyak

Mr. Polyak received his B.S. in Aerospace Engineering in 1979 from Pennsylvania State University. He is the Deputy Test Director responsible for Army Aviation Systems under the JLF Program at ARL, Aberdeen Proving Ground. He is also the EAPB Aircraft Systems Engineering Analysis Team Leader. Mr. Polyak may be reached at 410-278-3605.

During the Vietnam War, more than 1,000 U.S. Army helicopters were shot down in combat. The ultimate cost in personnel killed and injured was considerable. In many of these incidents, aircraft with limited or no ballistic vulnerability reduction features were defeated by small-arms fire in a "low-intensity" air defense environment. Some helicopter types went into battle without having been tested or even analyzed for vulnerability. Lessons learned from this pivotal experience brought about (and continue to influence) ballistic survivability specifications for Army helicopter systems. Motivated first by invulnerability design requirements for its new systems and, since 1987, reinforced by requirements of congressional Live Fire legislation, gunfire testing has become an important part of the process used by the Army to understand and influence helicopter system ballistic vulnerability design performance before production and fielding decisions are made.

Figure 1. UH-60A Black Hawk and AH-64A Apache helicopters.

Since the mid-1970s, ballistic vulnerability testing of Army helicopters has occurred in three primary arenas: 1) as part of system development and system upgrade programs, 2) under the Joint Live Fire Program, and 3) in compliance with the Live Fire Test (LFT) law (Title 10 U.S.C. 2366). These distinct but complementary test initiatives have helped reduce the vulnerability of current Army frontline combat helicopters compared to earlier systems. As current Army rotorcraft are being modernized and their service life extended (e.g., AH-64A Apache to the AH-64D Apache Longbow) and/or are the basis for derivative models (e.g., UH-60A/L to the MH-60K and UH-60Q), survivability payoffs are still realized from the original vulnerability reduction investments.

The UH-60A Black Hawk and AH-64A Apache (see Figure 1) helicopter development programs (1972–1978 and 1976–1984, respectively) were the Army's first to emphasize ballistic vulnerability testing. Two categories of tests were conducted; both focused on achieving invulnerability design requirements in the aircraft prime item development specifications (PIDS). Initially, design support tests (defined by the prime contractor) addressed designers' needs for information on damage resistance/tolerance of materials and candidate component configurations. Detailed designs were influenced by these test results. Later, prior to production, the Army planned and conducted invulnerability verification tests to ensure that proposed final designs of select nonredundant flight-critical subsystems and components met the PIDS requirements. As a result, both the Black Hawk and Apache were fielded with a high level of confidence in their ballistic survivability. A similar multiphase test approach, augmented by exit-criteria vulnerability tests and LFT events, is planned for the RAH-66 Comanche helicopter now in development.

Sponsored by the Director, Operational Test and Evaluation/Live Fire Test, the Joint Live Fire (JLF) Program began in 1984. A consistent, primary JLF objective has been the generation and maintenance of empirical vulnerability data on fielded U.S. weapon systems. To date, 21 test projects representing nearly 650 ballistic firings have been completed on the UH-60A and AH-64A under the JLF Program. This vulnerability database, the most comprehensive of its kind for helicopters, includes results for component- through system-level targets, often tested under flight-representative operating conditions,

Figure 2. Apache Longbow helicopter live fire test.

Figure 3. OH-58D Kiowa Warrior, the CH-47 Improved Cargo Helicopter, and the RAH-66 Comanche.

strategy development. Helicopter system LFT planning, conducting, and reporting (including damage assessments) are the responsibility of ARL/SLAD. Army helicopters with pending LFT requirements include the OH-58D Kiowa Warrior, the CH-47 Improved Cargo Helicopter, and the RAH-66 Comanche

against all primary threat projectiles. Select mission equipment, as well as traditionally emphasized flight critical elements of both systems, was examined. Recommendations for survivability enhancements based on the test results were submitted to Army aviation systems managers and shared with helicopter manufacturers. The JLF data are valuable to vulnerability analysts working with these systems, derivative systems (including Navy variants of the UH-60), and future rotary-wing aircraft. Army helicopter JLF efforts now in progress include ballistic firings against the AH-1S Cobra to support analytical vulnerability model evaluations and a planning study to determine potential future testing of the CH-47D Chinook.

Since passage of Live Fire legislation, three Army helicopters have undergone associated ballistic vulnerability testing: the AH-64D Apache Longbow (LBA) in 1995 (see Figure 2) and the MH-60K and MH-47E Special Operations Aviation (SOA) aircraft in 1997. These LFTs were conducted by the U.S. Army Research Laboratory, Survivability/Lethality Analysis Directorate (ARL/SLAD) at Aberdeen Proving Ground, Maryland. The LBA and SOA LFTs successfully addressed systems' specific vulnerability issues and data voids and initiated follow-on actions to further improve ballistic survivability.

Live Fire Test and Evaluation (LFT&E) procedures relevant to Army weapon systems are found in two documents: the DoD 5000 series directives and regulations and Department of the Army Pamphlet 73-6. The Operational Test and Evaluation Command is responsible for Army LFT&E

(see Figure 3). The AH-64D LBA is also slated to undergo engine compartment fuel-fire ballistic vulnerability LFT after a halon replacement extinguishing agent is selected.

History—what has it taught us? Ballistic threats continue to be encountered regularly worldwide by Army helicopters committed to military operations. Future scenarios will be no different, except more challenging. However, as shown in Grenada, Panama, Kuwait, Somalia, and elsewhere, Army helicopter systems designed and built to reduce ballistic vulnerability, and strengthened by gunfire testing, can and will survive. Recalling the Vietnam War experience, nothing less is acceptable.

The JTCG/AS Methodology Subgroup conducted a Mission-Level Analysis Workshop (MLAW) in Colorado Springs, Colorado, on 21–22 April 1998. The workshop began the process of establishing requirements for a joint mission-level analysis capability. Over 80 people attended the workshop, with subgroup chairman Dave Hall acting as emcee on the first day for presentations from 15 DoD and 9 DoD-related agencies on their mission-level analysis needs. On the second day, Methodology Integration Committee chairman Bob Meyer acted as facilitator for an extended brainstorming session on identifying and organizing specific requirements for a tool(set) to support mission-level analysis. The JTCG/AS Methodology Subgroup will sponsor follow-up MLAW workshops later this year and early next year to further develop a consistent tri-service approach to Integrated Survivability Assessment (ISA). For more on ISA, see “Integrated Survivability Assessment: Measuring the Balance” by Dave Hall, Aircraft Survivability, Spring 1998.

Ray Flores has left the JTCG/AS Central Office for reassignment to Wright-Patterson AFB, Ohio. Ray served in the Central Office for 3 years as the Air Force civilian representative, Survivability Methodology Subgroup monitor, and, most recently, as the Central Office Director. Just prior to his reassignment to the Air Vehicles Directorate, Air Force Research Laboratory, Ray graduated from the Advanced Program Managers Course at the Defense Systems Management College, Ft. Belvoir, Virginia. Ray has also been selected to participate in the prestigious Defense Leadership and Management Program. Good luck, Ray.

The Central Office is losing Air Force Major Dick Lockwood to retirement. Dick served in the Central Office for three years as the Air Force military representative, the editor of this newsletter, and as the Survivability Methodology Subgroup monitor. Good luck, Dick.

LFT&E Hits the Mark on Web!

The Live Fire Test and Evaluation (LFT&E) officially debuted on the World Wide Web (WWW) in April 1996. The Website allows real-time exchange of information among a wide spectrum of people from both government and industry.

When you visit the Website, you’ll find, among other items, a link to the innovative LFT&E Extranet, a limited access system tracking the weekly report of each weapon system with input from both government and industry action officers.

Future plans for the LFT&E website include an interactive form to determine whether a system qualifies for the LFT&E process, a secure area for contractors to upload their proposals, statements of work, and monthly reports, plus an LFT&E chat room for sharing ideas .

For more information, visit the LFT&E website at: http://www.dote.osd.mil/lfte.

Calendar of Events

Event	Date	Location	POC
Aircraft Fire Protection & Mishap Investigation	3-7 Aug 98	Dayton, OH	AFP Associates 937-435-8778
NDIA & AOC: LO & CM - Complementary Capabilities for Survivability	18-20 Aug 98	Monterey, CA	Joe Hylan 703-522-1820
AHS: Crash Safety Challenges & Innovative Solutions	14-17 Sep 98	Phoenix, AZ	Dr. Akif Bolukbasi 602-891-5111
AOC: EO/IR Conference	23-24 Sep 98	Adelphi, MD	AOC 703-549-1600
AHS: 1st Rotorcraft Requirements & Programs	1-2 Oct 98	Alexandria, VA	AHS 703-684-6777
Aircraft Fire and Explosion Course	Fall 98	Boston, MA	Dr. Moussa, 617-661-0700 www.blazetech.com
AHS and AAAA: HELMOT VIII	27-29 Oct 98	Williamsburg, VA	Jerry Irvine 757-858-3272

Information for inclusion in the Calendar of Events may be sent to: SURVIAC, Washington Satellite Office, 8283 Greensboro Dr., Allen 663D, McLean, VA 22102, Attn: Christina Wright 703-902-3176, FAX 703-902-3425.

Who? Where? What?

We don't want you to miss a single issue of *Aircraft Survivability*. Please take a few moments to review the address below and confirm that your name and address are correct. Or, if you would like to be added to our distribution list simply copy and complete this page and fax to 937-255-9673.

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